UNCLASSIFIED
SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

AD A038904

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER ARCSL-TR-77020	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) SUPPRESSIVE SHIELDING FOR HAZARDOUS MUNITIONS PRODUCTION OPERATIONS		5. TYPE OF REPORT & PERIOD COVERED Technical Report September 1975–December 1976
		6. PERFORMING ORG. REPORT NUMBER EM-TR-77013
7. AUTHOR(s) Bruce W. Jezek		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS Director, Chemical Systems Laboratory Attn: DRDAR-CLC-E Aberdeen Proving Ground, Maryland 21010		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS PA, A4932 Project 5761264
11. CONTROLLING OFFICE NAME AND ADDRESS Director, Chemical Systems Laboratory Attn: DRDAR-CLJ-I Aberdeen Proving Ground, Maryland 21010		12. REPORT DATE April 1977
		13. NUMBER OF PAGES 37
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)		15. SECURITY CLASS. (of this report) UNCLASSIFIED
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE NA

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

Copies available from: National Technical Information Service, Springfield, Virginia 22151.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Fire	Suppressive shielding
Blast	Hazardous munitions production operations
Fragmentation	

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Suppressive shields are steel composite enclosures developed by Edgewood Arsenal engineers. They contain 100 percent of the fragments from an accidental detonation and suppress hazardous blast and flame effects to a safe level.

Edgewood Arsenal has obtained DOD Explosives Safety Board approval for five groups of suppressive shields for protection of hazardous munitions production operations in US Army

(Continued on reverse side)

410 170

20. ABSTRACT (Contd)

ammunition plants. Safety-approved shields range in size from the 2-foot-diameter steel shell (shield group 6) to the 10-foot-diameter steel cylinder (shield group 3).

Engineers and scientists at Edgewood Arsenal have conducted a series of in-depth studies to develop methods and procedures for the accurate prediction of shield design parameters. It was found early in the program that inadequate information was available for accurately predicting the effects of blast, fire, and fragmentation that would occur during the accidental detonation of an explosive in a munition operation. Technology studies were conducted to develop engineering-design procedures in handbook form for use by plant engineers so that they could adequately design suppressive shields for incorporation in expanded- and modernized-US-Army ammunition facilities.

This paper will present details on safety-approved shields and will review technology studies to present some of the results which will be incorporated in the suppressive shield engineering-design handbook by June 1977. The completed and safety-approved engineering-design handbook is expected to be available by the end of calendar year 1977.

PREFACE

The work described in this report was authorized under PA, A4932 Project 5761264, Advanced Technology for Suppressive Shielding of Hazardous Production and Supply Operations. This work was started in September 1975 and completed in December 1976.

Reproduction of this document in whole or in part is prohibited except with permission of the Director, Chemical Systems Laboratory, Attn: DRDAR-CLJ-I, Aberdeen Proving Ground, Maryland 21010; however, DDC and the National Technical Information Service are authorized to reproduce the document for United States Government purposes.

CONTENTS

PRECEDING PAGE BLANK-NOT FILMED

SUPPRESSIVE SHIELDING FOR HAZARDOUS
MUNITIONS PRODUCTION OPERATIONS

I. INTRODUCTION.

Individual buildings in ammunition plants are widely dispersed in accordance with DOD and Army safety regulations (AR 385-64, DOD 5154.47, and TM 9-1300-206). The large distance between these buildings is required for the protection of operating personnel in adjacent buildings and to reduce facility damage to an acceptable level in the event of an accidental explosion. The current policy applied to the design of manufacturing facilities at the numerous Army ammunition plants is to specify concrete barricades, cubicle structures, and shelters. A typical cubicle is shown in figure A-1, (appendix). Laced-, reinforced-concrete barricades and structures constructed in accordance with a joint Army, Navy, and Air Force technical manual, TM 5-1300, entitled Structures to Resist the Effects of Accidental Explosions,[1] contain the sensitive explosive materials or processing equipment.

Barricades are used to prevent propagation of the explosion from one area to the next by separating the quantities of potentially detonable materials or hazardous process steps; they do not prevent leakage of the high-blast pressures or wide dispersal of damaging primary and secondary fragments generated when a detonation occurs. Shelters, on the other hand, are designed to totally contain the effects of an explosion. They must be designed to withstand the very high overpressures generated by reflections from their solid surfaces.

Typically, barricades and shelters are both fixed plant installations and are a severe constraint to plant rearrangement which may be necessary as a result of process changes. In addition, this places undesirable constraints on the production output of a facility and requires higher capital investments to attain a desired production objective and, in many cases, is the limiting factor in the rate of production attainable. To avoid these problems, plant designers have resorted to greater separation distances and special orientation of buildings to minimize the need for laced-, reinforced-concrete barricades and shelters. This, of course, necessitates greater initial commitments in real estate and, on a long-term operational basis, is the cause for higher operating costs due to extended-utilities services and the need to transport personnel and material greater distances to and from work stations.

Suppressive shields are steel composite enclosures developed by Edgewood Arsenal engineers. They contain 100 percent of the fragments from an accidental detonation, suppress hazardous blast and flame effects to a safe level, and offer an opportunity to reduce production costs and to avoid inflexible plant arrangements.

This paper will present details on safety-approved shields and will review technology studies to present some of the results which will be incorporated in the suppressive-shield engineering-design handbook by June 1977.

ACCESSION for
NTIS White Section
DDC Buff Section
UNANNOUNCED
JUSTIFICATION
BY
DISTRIBUTION/AVAILABILITY CODES
Dist. AVAIL. and/or SPECIAL
A

PRECEDING PAGE BLANK-NOT FILMED

II. SAFETY-APPROVED SUPPRESSIVE SHIELDS.

The Department of Defense requires that safety approval be obtained for protective shields that surround a hazardous operation. Five suppressive shields have been designed, fabricated, proof-tested, and safety-approved by the DOD Explosives Safety Board. These shields will be used in US Army ammunition plants that are being modernized and expanded under the Army's Munitions Production Base Modernization and Expansion Program.

A brief summary of each shield is provided in this section. Additional information on these shields is provided in a previous report[2] which describes the safety approval specifications for each shield. Details of the design, analysis, test plan, and test results for the five safety-approved shields are provided in previous publications.[3-9]

These safety-approved shields consist of three basic types: (1) cylindrical, interlocked I-beams, (2) rectangular box, and (3) spherical shells; these can be used in hazardous operations involving 37 pounds of explosive material or 30 pounds of pyrotechnic material. The characteristics of these safety-approved shields are summarized in table 1. This table indicates the operator's safe distance, i.e., the distance from the shield exterior wall that an operator can be located (stationed) and not be injured by the blast pressure venting out of the shield from an explosion inside the suppressive shield.

Table 1. Safety-Approved Suppressive Shields

Shield type	Material limit	Operator safe distance	Size
		ft	ft
Group 3	37 lb of pentolite	6.2	11.25 diameter × 10 height
Group 4	9 lb of pentolite	19	9.2 × 13.1 × 9.3 height
Group 5	1.84 lb of C-4	3.7	10.4 × 10.4 × 8.5 height
	30 lb of illuminant mix	2	
Group 6	13.6 oz of pentolite	1	2 diameter
81 mm	Two 81 mm rounds 2.8 lb of C-4	3	14 × 18.7 × 12.4 height

Suppressive shields were originally conceived as vented structures with a large percent of the total surface area being open, i.e., 20 percent. The purpose of the venting was to attenuate the blast pressure and fireball from a hazardous reaction -- detonation, deflagration, or burning of hazardous material. This venting was controlled by using a series of nested structural members. For the rectangular-type suppressive shields (shield groups 4, 5, and 81 mm), the venting is shown in figure A-2.

Recent suppressive shield designs have increasingly controlled the venting to meet requirements of applying these shields to specific applications. The group-3 shield shown in figure A-3 has an effective venting ratio, α_{eff}, of 0.4 percent, which is required to attenuate the external blast pressure by 80 percent at the interline distance.[10] The initial design of the group-3 shield consisted of interlocked I-beams that formed the cylindrical portion of this structure; however, certain tests[3] indicated excessive external pressure requiring the addition of closure strips and liner to the interior of the I-beam cylinder to reduce the pressure to acceptable levels. Figure A-4 shows a detail of the cylinder.

The group-6 shield (figure A-5) is a unique spherical design. The requirement for this shield is that an operator be capable of transporting, on a push-type cart, small quantities of extremely hazardous primary-explosive material. Due to the close proximity of the operator to the shield and the hazardous materials involved, it is not feasible to allow any gas pressure to vent the shield. Use of this shield concept will result in a $2,800,000 savings at Iowa Army Ammunition Plant. A number of pushcarts with the group-6 shield mounted to the cart will replace an automated conveyor system which was planned to transport the hazardous material between locations in the production facility.

Group-4 shield testing was conducted at Dugway Proving Ground, Utah. This rectangular-type shield (figure A-6) is safety-approved for use in hazardous operations involving two 105-mm high-explosive projectiles or an equivalent explosive yield, i.e., 9 pounds of 50/50 pentolite. A rotating product door which allows munitions to pass through the shield on a conveyor was also successfully tested in this shield.

Figure A-7 illustrates the product door which mounts in the shield wall. The door is designed to achieve greater pressure attenuation than the shield panel and prevent fragment escape. The three-lobed configuration was selected to match the conveyor speed and allow proper interface with the incoming projectiles. Figure A-7 shows an 81-mm M374 mortar projectile located on a conveyor and passing through the shield. The conveyor is continuous through the shield wall and the projectiles remain on the conveyor at all times. The product-door lobe simply surrounds the projectile during passage into the shield.

The group-5 shield (figure A-8) is a rectangular type and has been successfully designed and tested for application to nonexplosive, deflagration-type materials such as pyrotechnic compositions and propellants. Thirty pounds of illuminant mix was ignited in this shield and the hazardous fireball resulting (figure A-9) was attenuated to a safe level several feet from the exterior of the shield. Figure A-10 indicates the suppression effects of this shield on the 30-pound illuminant mix.

The third rectangular shield is the 81-mm shield which is safety-approved for use in hazardous operations involving three 81-mm M374 mortar projectiles or an equivalent explosive charge. The basic shield is shown in figure A-11. This shield will be the first shield to be installed in an Army ammunition plant (on Line C at Milan Army Ammunition Plant). Figure A-12 illustrates the shield surrounding the fuze-cavity-facing operation. The prototype 81-mm shield size has been reduced by one panel length to reduce the shield cost. Illustrated in the figure are numerous penetrations required to make the shield operational such as utility lines, vacuum line, and conveyor penetration.

These safety-approved shields are available for use and can be designed and configured to meet the specific requirements of any given application and still provide the desired protection. The modular characteristic allows greater flexibility in plant line layouts. In munition plants where pilot lines are investigated, these shields can be moved to meet the requirements of the specific operation.

III. SUPPRESSIVE-SHIELDING TECHNOLOGY PROGRAM.

A. Overview.

Technology development of suppressive shields has proceeded along the lines illustrated on the flow chart in figure A-13. In the event of an accidental detonation, blast, fragment, and fireball hazards result. Definition of these hazards is essential to the design of a shield. Each of these hazards poses a special problem to the designer and requires consideration, not only singularly but synergetically. Defining procedures to predict the suppression of the blast, fragment, and fireball hazard is the next step in the technology development. Consideration of the loading imposed on the structure and the associated structural response is necessary to provide a safe shield. The hazard suppression requirements must be satisfied, as well as the structural requirements, and tradeoffs made in the design to obtain the best shield.

Edgewood Arsenal has been the lead agency for suppressive-shielding technology development and has obtained support from the agencies listed in table 2. Ballistics Research Laboratories located at Aberdeen Proving Ground, Maryland, has been tasked with major efforts in the areas of blast and fragment definition, blast and fragment suppression, fireball definition, and structural analysis. The National Aeronautical and Space Administration (NASA) National Space Technology Laboratories located in Bay St. Louis, Mississippi, has been used to perform testing in suppressive shields fabricated as part of the hardware development program. Extensive instrumentation was used to record blast pressure data and structural response data for verification of predictive analytical techniques. The Naval Surface Weapons Center, formerly Naval Ordnance Laboratory, at White Oak, Maryland, provided blast codes for defining gas pressures inside suppressive shields. Southwest Research Institute has provided contractual support in all analytical development areas and has developed scale model laws for defining the blast pressure attenuation outside suppressive shields.

Prior to designing a suppressive shield, the scenario for the specific application of the shield must be defined. This could be simply a matter of describing the characteristics of the explosive, i.e., yield, type, and shape, for application of suppressive shields to explosive storage, or

Table 2. Applied Technology Participants

Ballistic Research Laboratories (BRL)

1. Major contributor
2. Develop technology in areas of:

   Blast

   Fragmentation

   Thermal

   Structural

NASA National Space Technology Laboratories (NASA-NSTL)

1. Test/fabrication support
2. Obtain applied data from group shields

Naval Surface Weapons Center (NSWC)
(Formerly Naval Ordnance Laboratory (NOL))

1. Technical support in:

   Blast codes

   Structural analysis

Southwest Research Institute (SWRI)
(Contractor)

1. Consultant services
2. Data analysis
3. Model/scaling law development

it could be very complex where hazardous operations involving equipment support the manufacture of a munition. Basically, this task requires describing "what is happening." Figure A-14 illustrates the machinery and associated support items involved in the cavity-facing operation of a high-explosive projectile. The location of the munition, its orientation, and the position of conveyors and other equipment surrounding the operation must be defined to allow prediction of the blast, fragment, and fireball threats that the shield will encounter. (This report will only address the blast and fragment aspects associated with suppressive shield technology development.)

B. Blast Environment.

The predictive capability is available in literature[11] for defining the incident and reflected pressure and impulse as a function of time for an explosive detonation in free air. This is illustrated in figure A-15 by the excellent correlation between the theory and the experimental data. This technology is known and available for use on the suppressive-shielding project. However, surrounding the explosive with a suppressive shield causes a more complex blast profile inside the shield. The shock waves resulting from the detonation are reflected off the shield walls and re-reflected many times inside the shield causing a nonuniform pressure loading on the shield.

The blast environment task is to define the blast field associated with suppressive structures. This requires the definition of the internal pressures, reflected and quasi-static, and the external incident pressure as a function of such parameters as charge size, shape, and geometry; shield-venting characteristics; and the shield configuration.

Figure A-16 depicts one wall of a suppressive shield with the reflected impulse in various positions indicated. The reflected impulse is appreciably higher in the corner locations of the shield. This loading profile must be addressed in the design of a suppressive shield. (The reflected impulse values shown are in psi-ms and are for the detonation of 1 pound of 50/50 pentolite in a 3-foot cubical shield attached to a concrete foundation.)

Another example of the pressure loading inside a shield is shown in figure A-17. This three-dimensional plot of the blast pressure was obtained from the WUNDY/DORF computer code prepared by the Ballistics Research Laboratories. Pressure is represented by the vertical axis with the Z-axis being the distance from the center of the charge to the shield roof and the R-axis being the distance from the charge to the shield wall. The reflected pressure for 45.7 pounds of 50/50 pentolite in the quarter-scale group-1 shield is plotted just after the initial shock wave has been reflected from the roof.

The second internal pressure of concern in the design of suppressive shields is the quasi-static pressure. When an explosion is confined in a fixed volume as in a suppressive shield, a long-term gas pressure results from the oxidation of the explosion products. This gas pressure buildup is termed the quasi-static pressure and is illustrated in figure A-18. The peak quasi-static pressure is normally much lower (162 versus 4000 psi for the illustration shown in figure A-18) than the reflected pressure, however, the duration is much longer (0.32 versus 50 milliseconds). Therefore, the quasi-static pressure must be considered in the structural loading. Prediction of this pressure is extremely difficult even though numerous methods exist for computing the quasi-static pressure. Attempts to accurately measure the quasi-static pressure also proved difficult since the

pressure gauge is first exposed to the high blast pressure. The gauge must be capable of withstanding this blast pressure, and yet accurately record the much lower quasi-static pressure.

One method to predict the quasi-static pressure was to use the Naval Surface Weapons Center INBLAS computer code to match the experimental results. By doing this, the peak quasi-static pressure would be approximately 200 psi for the data plotted in figure A-19. This value results for the 45.7-pound 50/50 pentolite charge used in the quarter-scale group-1 shield.

C. Blast Attenuation.

Blast attenuation in a suppressive shield is achieved by a controlled venting of the pressure through various combinations of nested structural members. Definition of these venting characteristics was achieved by conducting shock tube tests using scale model suppressive panels and explosive tests in scale model suppressive shields. The 10-cm shock tube at the Ballistics Research Laboratories was used to investigate the effects of venting on pressure attenuation. By varying the venting conditions such as the hole diameter, number and vent area for perforated plates, the effects of each parameter on the pressure attenuation was determined. Figure A-20 illustrates the effect of one design parameter, the hole size in a perforated plate, on pressure attenuation. For the conditions tested (in this case, constant vent area), pressure attenuation was independent of hole size. Ballistics Research Laboratories has published several reports summarizing these tests.[12-14]

Using model analysis techniques and experimental data from numerous scale-model and prototype tests, an equation for predicting the blast pressure outside a suppressive shield was developed by Southwest Research Institute using nondimensional analysis techniques. The equation shown in figure A-21 is dependent on the explosive yield (W), vent ratio (α), standoff distance from the charge (R), and width of the shield (X). Use of this equation allows the prediction of external pressure based on any given set of shield design parameters. It should be noted that suppressive structures are designed to meet the user's requirement and, in Army ammunition plants, safety requires that pressures at operator locations not exceed 2.3 psi (peak side-on or incident pressure). Knowing the pressure level (P_S), the standoff distance (R), and the shield size (X) allows the vent ratio (α) to be determined and incorporated in the shield design.

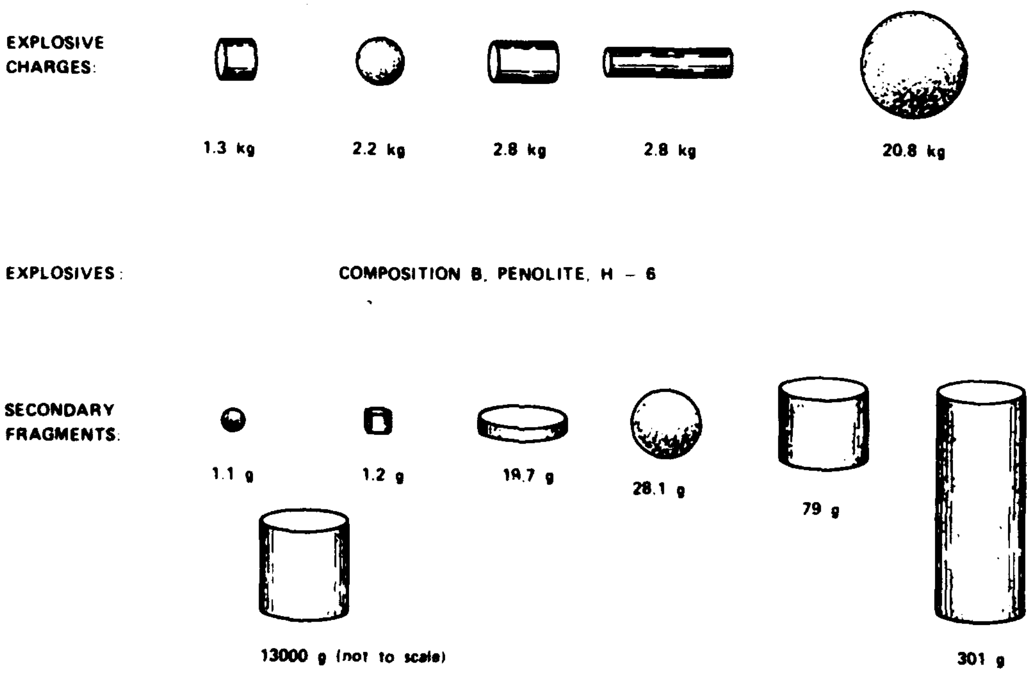
D. Fragment Environment.

The second major element to be considered in the design of a suppressive structure is the fragmentation threat. When a detonation occurs, the blast pressure accelerates the munition components and items surrounding the munition to high velocities, posing a severe hazard to operating equipment and personnel. Fragment hazards are classified as: (1) primary – those fragments in direct contact with the explosive such as the shell casing of a high-explosive projectile, and (2) secondary – those fragments not in immediate contact with the explosive material. For example, parts of the equipment shown in figure A-22 are defined as secondary fragments and require special consideration. Items such as rollers for rotating the munition during fuze assembly operations, the roller shaft, and the like are all classified as secondary fragments. Though more massive than the small, high-velocity primary fragments of a high-explosive projectile, in some instances, these secondary fragments pose a more severe threat.

Data exists in the Joint Munitions Effectiveness Manual[15] for defining the mass and velocity of primary fragments from various munitions. These data were obtained by exploding a munition in a circular arena and catching the fragments in a soft media (wall board). This allowed determination of individual fragment mass and velocity which are essential parameters for predicting the fragment hazard.

To establish methodology to predict the secondary fragment characteristics, an experimental model test program was developed. Table 3 lists the explosive charges, explosive types, and secondary fragments used in the conduct of these tests. These parameter values were selected to cover the range of values anticipated from an accidental detonation in an Army ammunition plant. The secondary-fragment experimental-test setup is shown schematically in figure A-23. The secondary fragment was located at a given standoff distance from the explosive, and the explosive was detonated propelling the fragment past an orthogonal bank of X-ray tubes. Analysis of the X-rays allows measurement of the fragment velocity. Both constrained and unconstrained fragments are being considered. Constrained fragments require additional energy to break the fragment from its constraints and must be addressed. These explosive tests are nearing completion at the Ballistics Research Laboratories on this technology phase.

Table 3. Experimental and Analytic Program



E. Fragment Containment.

Suppressive shields are designed to contain all fragments resulting from accidental detonation. A complementary test program and model analysis have been conducted to establish methodology to predict the fragment-stopping capability of suppressive structures. Panel parameters such as spacing, thickness, and configuration and fragment parameters such as mass, velocity, geometry, and area have been incorporated in this investigation.

The test program was conducted using a large-bore gun (figure A-24) to ballistically launch controlled fragment shapes at various suppressive panels. Figure A-25 illustrates a small section of a suppressive panel which the gun-launched fragment impacted. These target panels were used to evaluate the effects of spacing on the fragment-stopping capability of suppressive panels. The striking velocity of the fragment was measured and orthogonal X-rays were used to determine the "behind-the-plate" mass and velocity after fragment penetration of the panel members. A typical series of X-rays, illustrating a cylindrical fragment simulator penetrating a segment of the 81-mm suppressive-shield panel, is shown in figure A-26. The fragment breakup can be observed along with the orientation. Data from these X-rays provide residual velocity data necessary to predict the fragment-stopping capability of a suppressive panel.

To develop an analytical model for predicting the fragment-stopping capability of a given panel design, the following parameters must be defined: striking velocity, striking mass, fragment-presented area, panel thickness, panel angle of obliquity, and the fragment orientation or impact angle. After penetration, the exit parameters must also be defined. These exit parameters are used as the input or striking parameters for the next layer in the suppressive panel.

Ballistics Research Laboratories has used the experimental test data to develop empirical models to predict fragment penetrations. The following equation is typical of the model for the fragment ballistics limit velocity:

$$VL = A_O M^{-1/2} A_p^m (T \sec \theta)^n$$

where

VL = Ballistic limit velocity, m/sec

A_p = Fragment-presented area, mm^2

T = Target thickness, mm

θ = Obliquity

M = Fragment mass, grams

A_O, m, n are empirical constants

	Light steel < 26 gr	Heavier steel
A_O	94.17	71.69
m	0.291	0.295
n	0.92	0.91

The limit velocity in the preceding equation is that velocity below which penetration of the suppressive shield will not occur. Ricchiazzi and Barb[16] provide details on this model.

The common practice for assessing the fragment-stopping capability of the target is to determine the V_R versus V_S, or residual velocity versus striking-velocity curve for a given target/fragment configuration. The residual velocity is defined as the fragment velocity after penetration. The data plotted in figure A-27 is for two spacing distances between two structural elements (in this case, a Z bar and a perforated plate) and indicates that the results are insensitive to the spacing parameter. The analytical model developed during the suppressive-shielding-technology program predicts the results shown by the dashed curve plotted on the V_R versus V_S graph. Excellent agreement between the theory and the experimental data is indicated.

To illustrate the progress made during the past year, the limit velocity predictions for secondary fragments emanating from the fuze torque operation on a 105-mm projectile are compared in figure A-28. The FY 75 predictions were best estimates prior to the technology development on the suppressive-shielding program. Accurate determination of the material thickness necessary for containment of fragment hazards is essential for the design of cost effective protective shields, and the reductions illustrated in figure A-28 will significantly affect the shield design and final cost.

IV. ENGINEERING-DESIGN HANDBOOK.

The technology development program will culminate with the preparation of an engineering-design handbook for suppressive structures. It is envisioned that this handbook will complement the existing design manual for laced-, reinforced-concrete walls (TM 5-1300) and incorporate the chapters listed below:

1. Safety-Approved Shields
2. Structural Details
3. Structural Damage
4. Explosive Environment
5. Structural Design and Analysis
6. Economic Analysis
7. Quality Assurance

The handbook will provide procedures for predicting the essential characteristics of a detonation for hazard description and procedures to design and/or select a suppressive shield for suppression of these hazards. Equations, tables, and figures to simplify the analysis will be included in the design manual. Typical sample problems will be worked out to assure understanding of the design procedures established.

V. SUMMARY.

Suppressive shielding has progressed to a point where these protective devices are available for immediate use in hazardous operations. With Edgewood Arsenal consultation assistance, shields can be designed for hazardous applications with explosive limits of up to 42 pounds of TNT (37 pounds of 50/50 pentolite) and 30 pounds of illuminant composition. Five suppressive structures have been successfully tested, indicating the feasibility of this new concept in protective structures. Experimental measurements taken during testing of these structures have verified the predictive techniques developed in the technology phase of the suppressive-shielding program. These procedures will be available in the near future in the form of an engineering-design handbook.

LITERATURE CITED

1. Department of the Army Technical Manual 5-1300. Structures to Resist the Effects of Accidental Explosions. June 1969.

2. Katsanis, D. J. EM-TR-76088. Safety Approval of Suppressive Shields. August 1976.

3. Schumacher, R., Kingery, C., and Ewing, W. BRL Memorandum Report 2623. Airblast and Structural Response Testing of a 1/4 Scale Category 1 Suppressive Shield. May 1976.

4. Schumacher, R. BRL Memorandum Report 2701. Airblast and Structural Response Testing of a Prototype Category 3 Suppressive Shield. November 1976.

5. Keetch, A. K. Dugway Proving Ground Report DPG-DR-C996A. Category 4 Suppressive Shield. November 1975.

6. Koger, D. M., and McKown, G. L. EM-TR-76001. Category 5 Suppressive Shield. May 1975.

7. Nelson, K. EM-TR-76096. Spherical Shields for the Containment of Explosions. March 1977.

8. Morris, L. T. EM-CR-74050. 81-mm Suppressive Shield. March 1975.

9. Koger, D. M., and McKown, G. L. EM-TR-76005. Supplementary Tests and Studies of the 81-mm Suppressive Shield. September 1975.

10. AMC Regulation 385-100. Change 2. Safety Manual. 12 September 1974.

11. Baker, W. E. Explosions in Air. University of Texas Press. 1973.

12. Kingery, C., and Coulter, G. BRL Memorandum Report 2664. Shockwave Attenuation by Single Perforated Plates. August 1976.

13. Ewing, W., and Schumacher, R. BRL Interim Memorandum Report 376. Blast Attenuation Outside Cubical Enclosures Made Up of Selected Suppressive Structure Panel Configurations. April 1975.

14. Oertel, F. BRL Report 1906. Evaluation of Simple Models for the Attenuation of Shock Waves by Vented Plates. August 1976.

15. Joint Munitions Effectiveness Manual. JMEM/AS-OSU Contract (U). Aberdeen Proving Ground, Maryland, v.d. Fr: AMSAA Contract Pt., 9 March 1973. SECRET Report.

16. Ricchiazzi, A., and Barb, J. BRL Memorandum Report 2578. A Tentative Model for Predicting the Terminal Ballistic Effects of Blunt Fragments Against Single and Spaced Targets. A Comparison of Predicted and Experimental Results. January 1976.

PRECEDING PAGE BLANK-NOT FILMED

APPENDIX

FIGURES

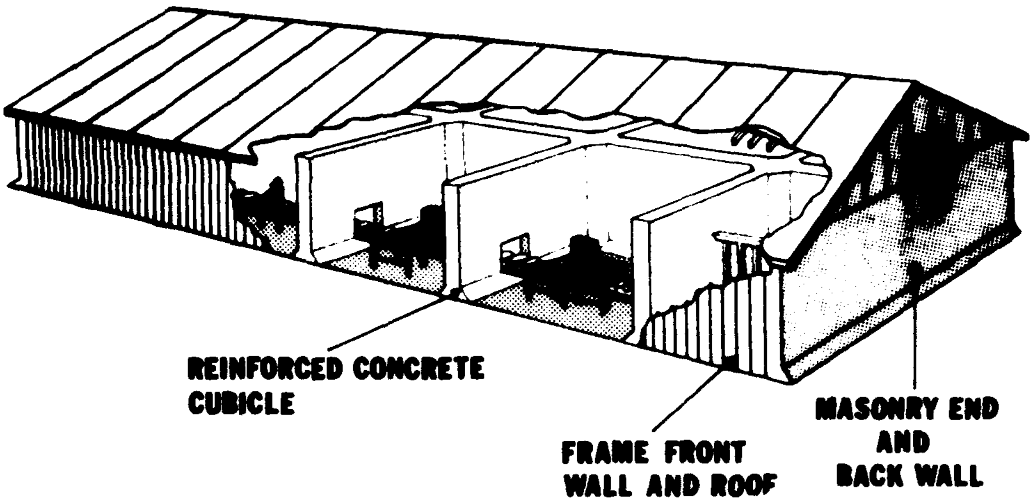


Figure 1. Conventional Structure

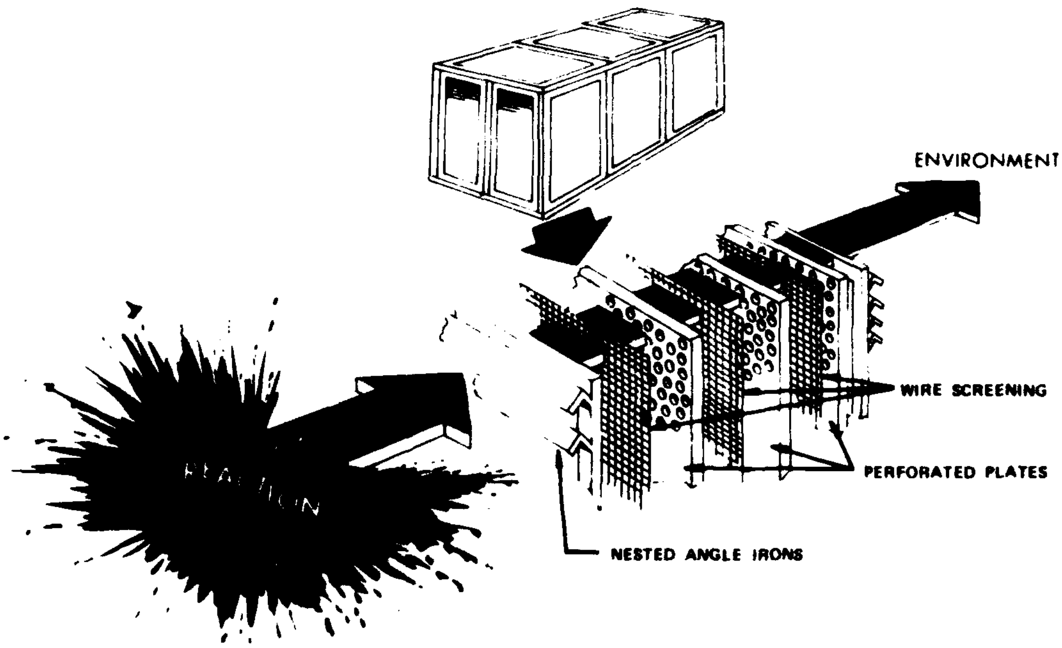


Figure 2. Rectangular Suppressive Shield Venting

PRECEDING PAGE BLANK-NOT FILMED

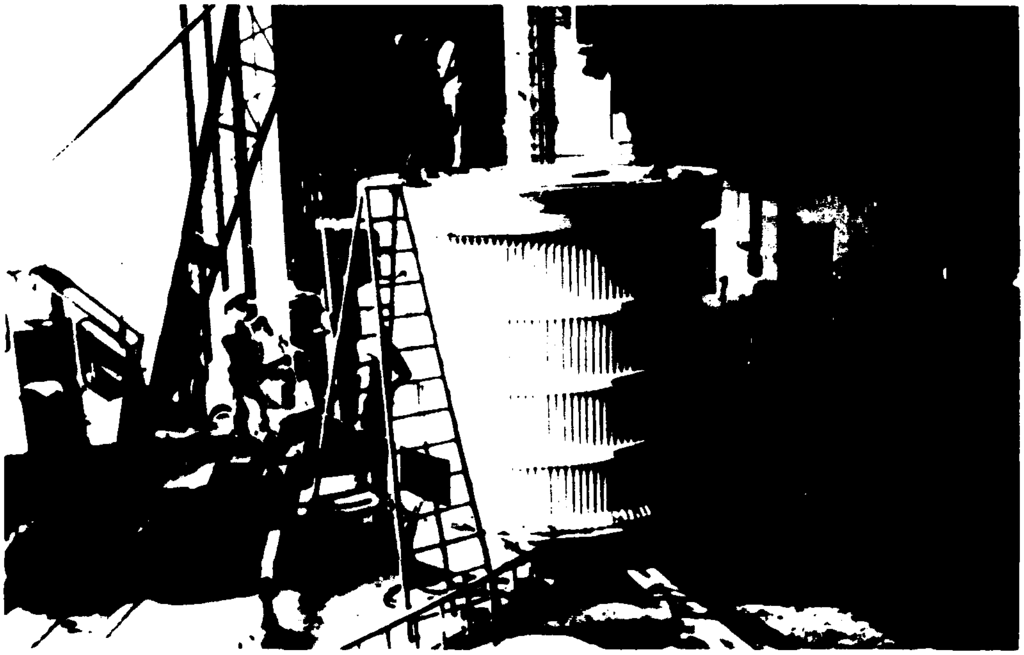


Figure 3. Group 3 Suppressive Shield

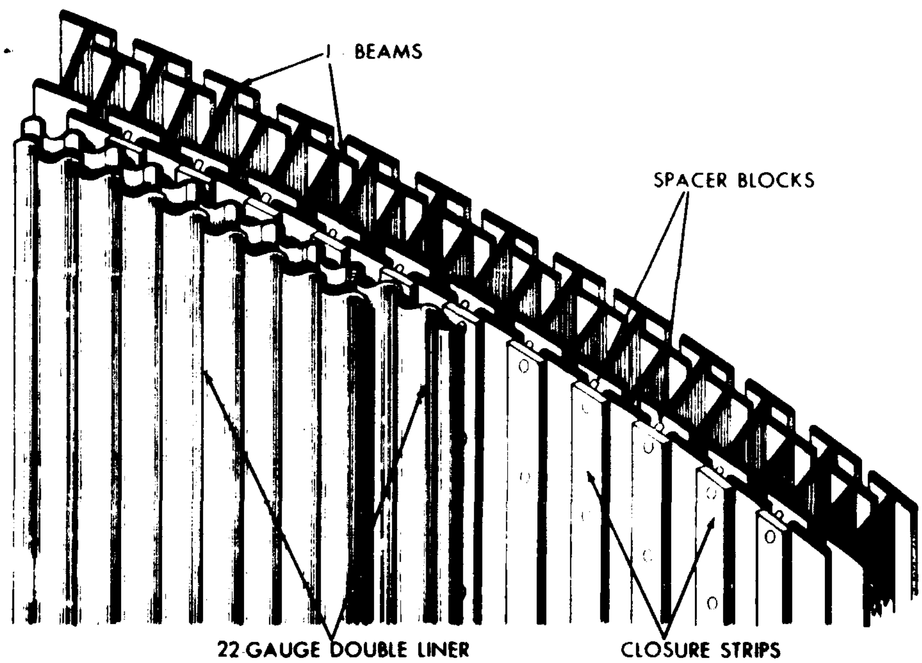


Figure 4. I-Beam Configuration Showing Addition of Closure Strips and Double Liner to Group 3 Shield

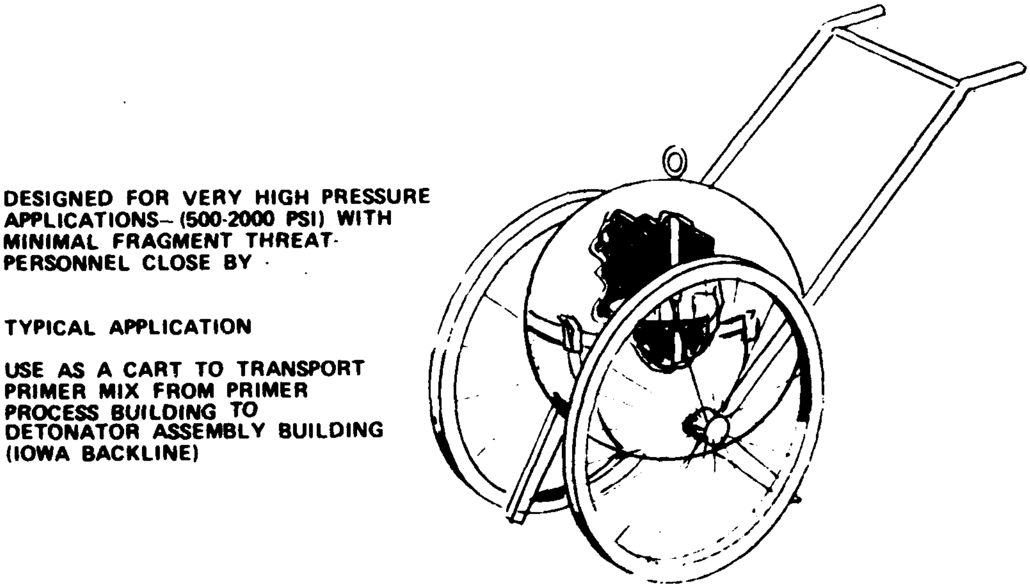


Figure 5. Group 6 Suppressive Shield

Figure 6. Group 4 Suppressive Shield

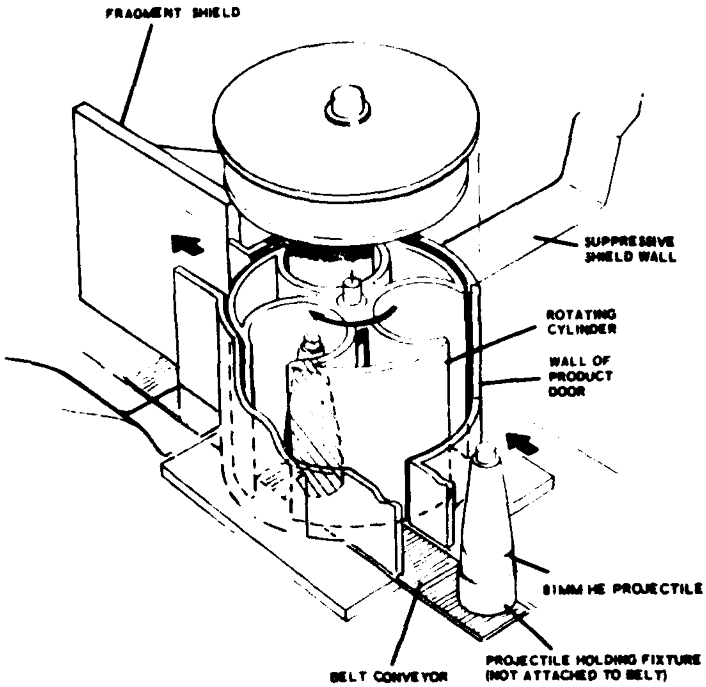


Figure 7. Rotary Product Door

Figure 8. Group 5 Suppressive Shield

Figure 9. Fireball of 30 Pounds of Illuminant Mix in Free Air

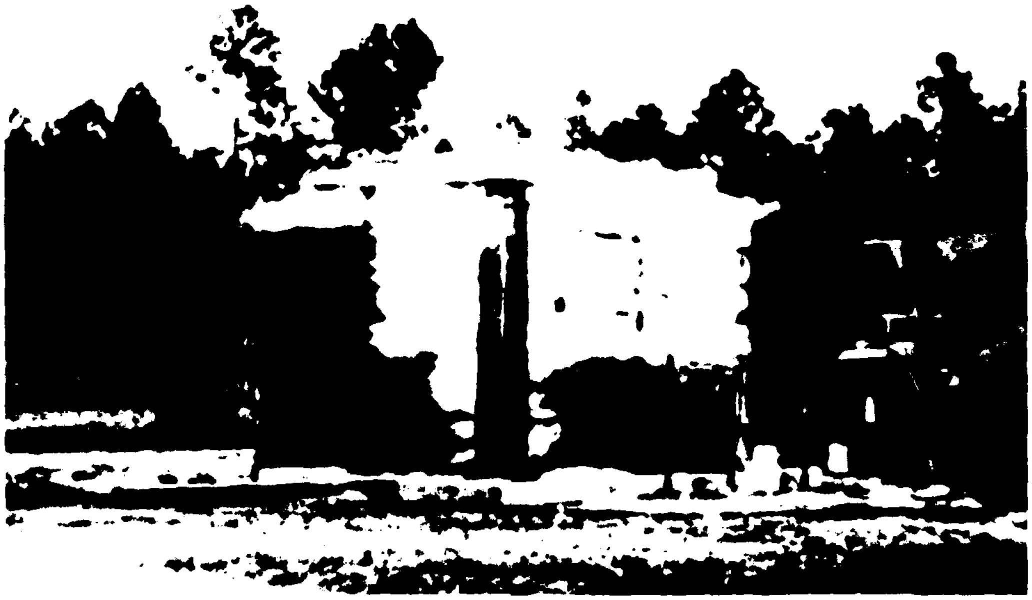


Figure 10. Suppressed Fireball of 30 Pounds of Illuminant Mix in Group 5 Shield

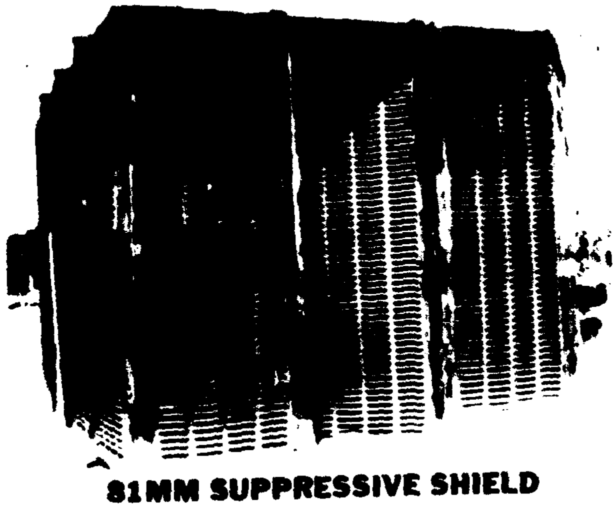


Figure 11. 81-mm Suppressive Shield

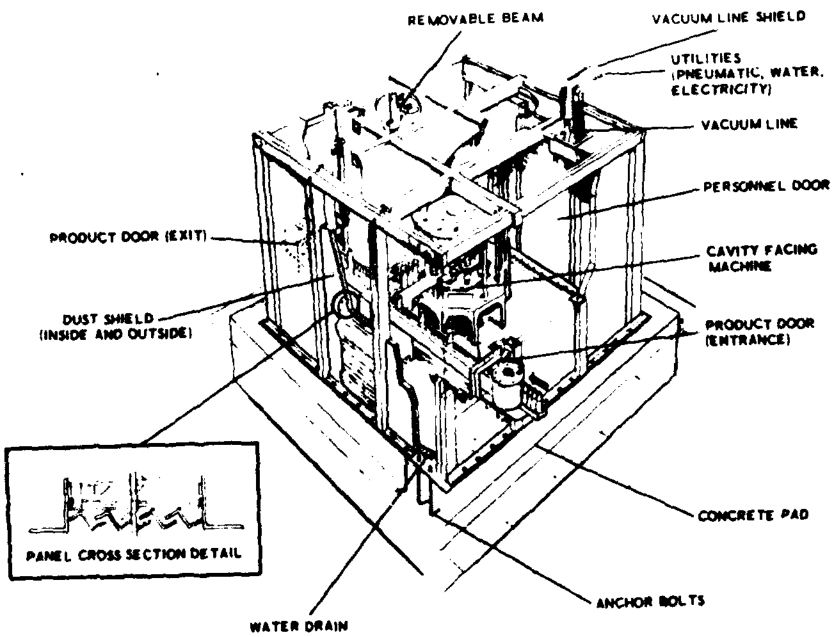


Figure 12. 81-mm Suppressive Shield Applied to Cavity-Facing Operation

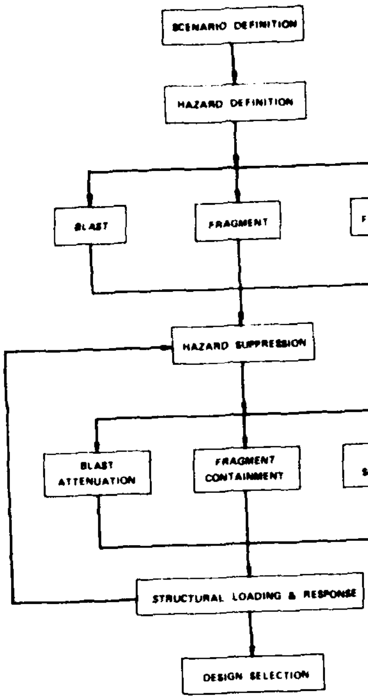


Figure 13. Technology Flow Chart

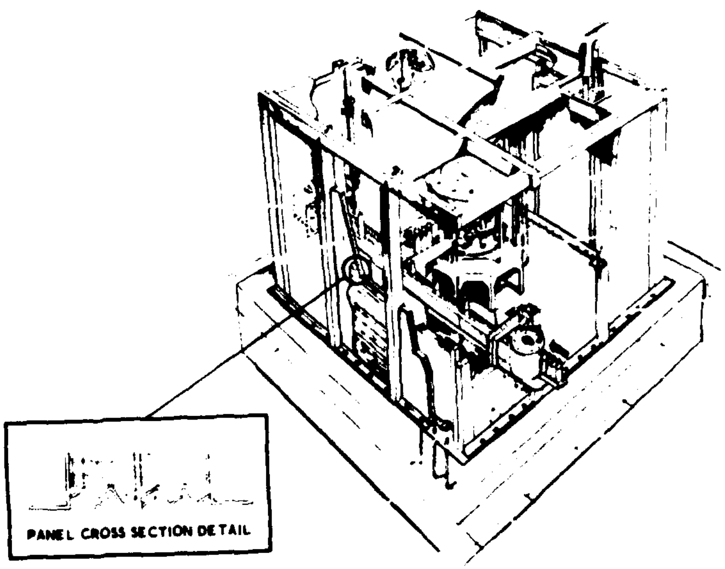


Figure 14. Cavity-Facing Operation

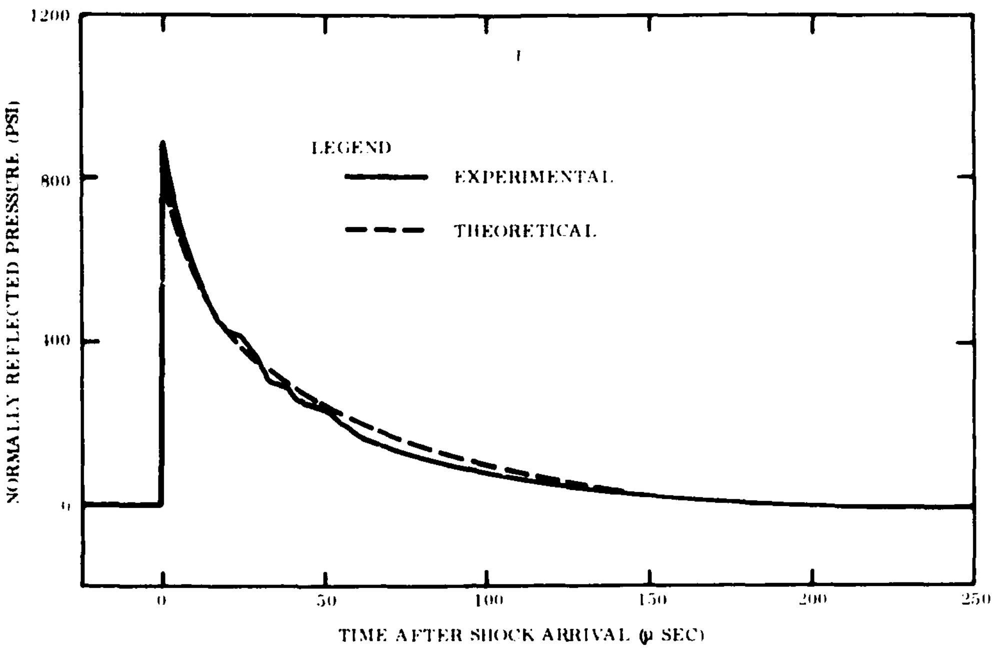


Figure 15. Free-Air Reflected-Pressure Comparison

661	464	464	464	661
464	403	385	403	464
464	385	363	385	464
464	403	385	403	464
661	464	464	464	661

Figure 16. Reflected Impulse for 1 Pound Pentolite

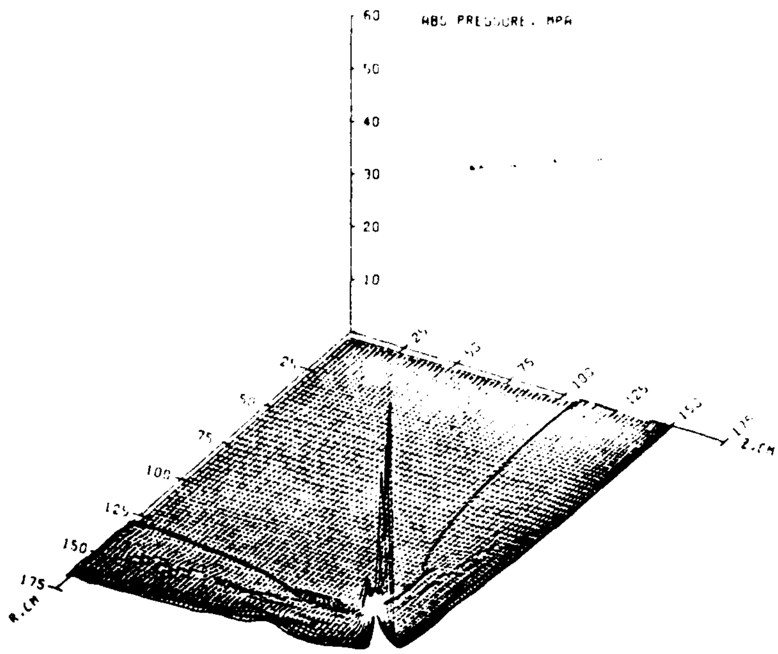


Figure 17. Three-Dimensional Plot of Blast Pressure from Quarter-Scale Group-1 Shield

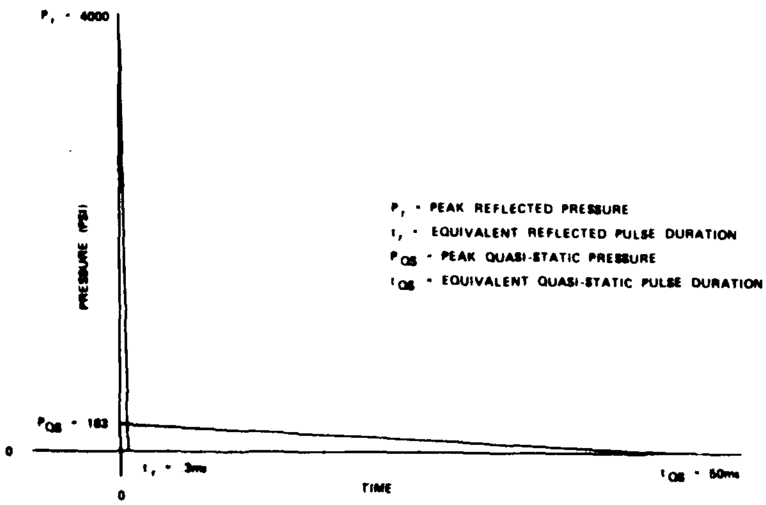


Figure 18. Equivalent Pressure-Time Histories for Quarter-Scale Group-1 Shield

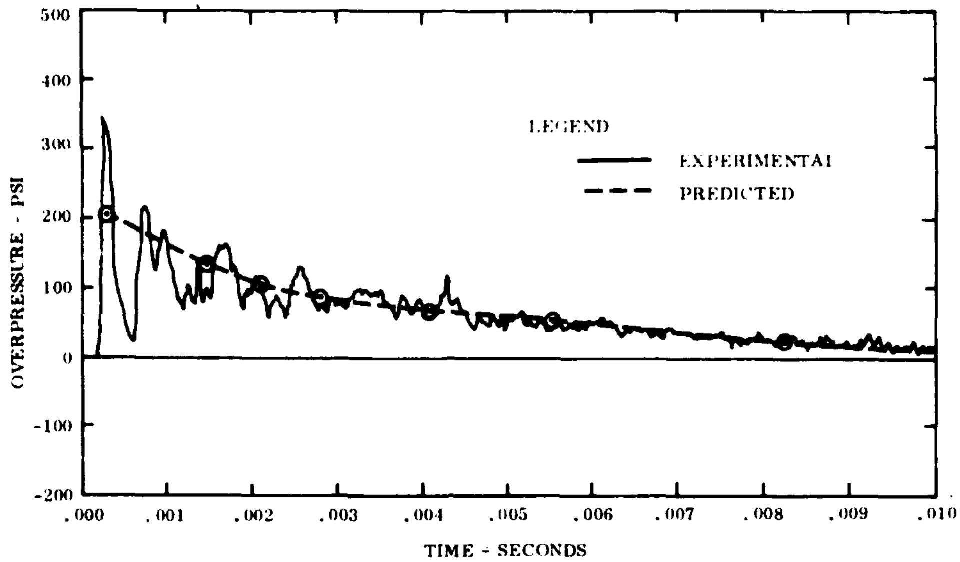


Figure 19. Quasi-Static Pressure Inside Shield

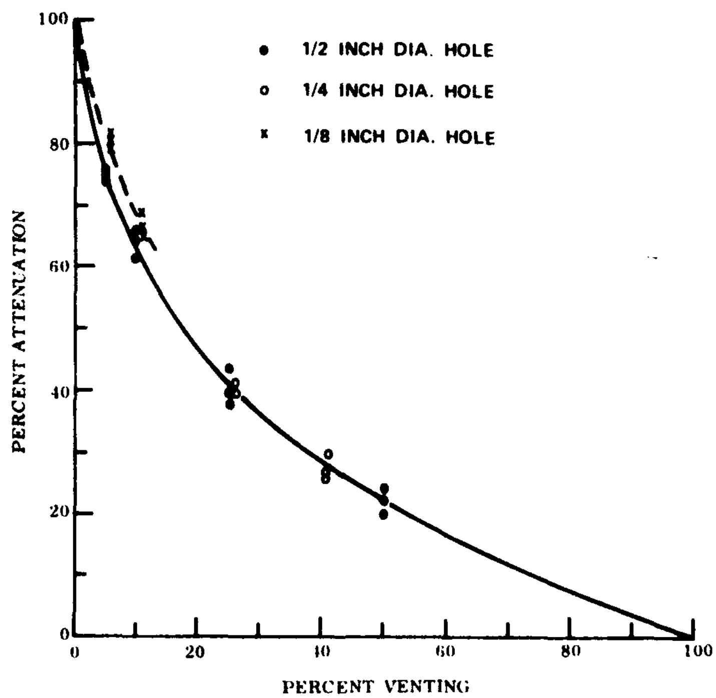


Figure 20. Percent Attenuation in Pressure Versus Percent Venting (from Shock Tube)

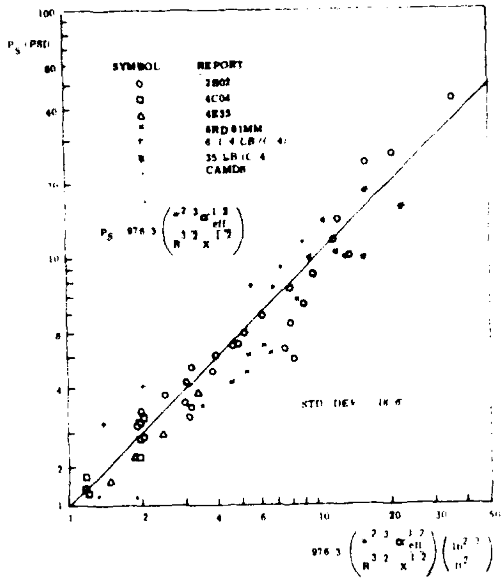


Figure 21. Curve Fit to Blast Pressures Outside Suppressive Structures

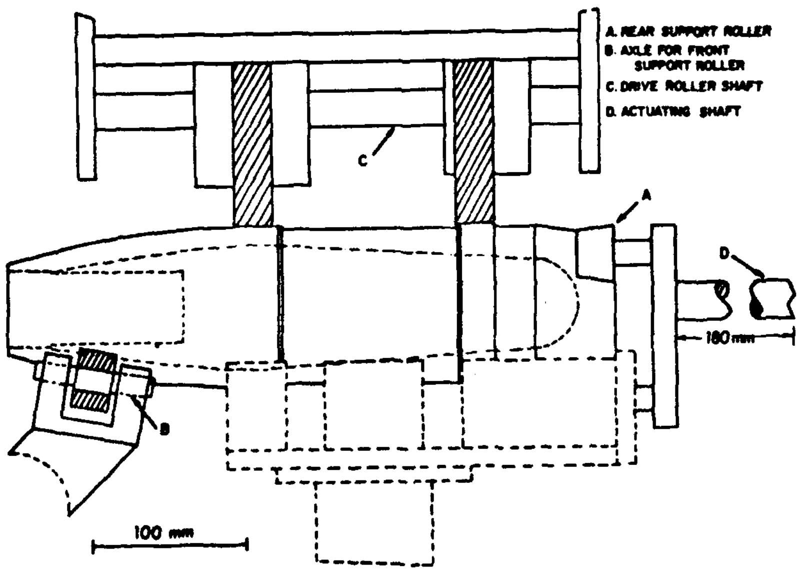


Figure 22. Secondary Fragment Problem: 105-mm M1 Fuze Torque Operation

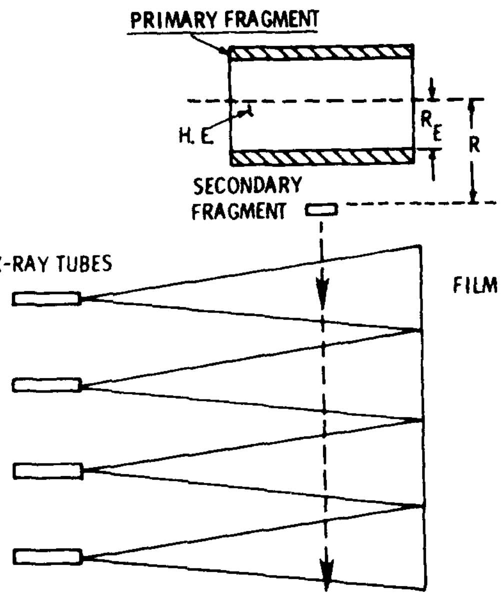


Figure 23. Secondary Fragment Test Setup

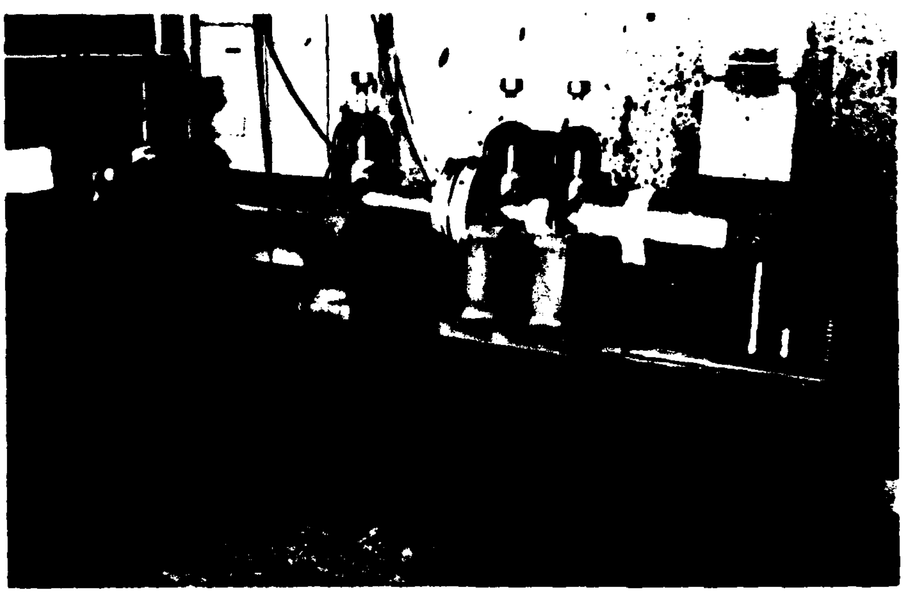


Figure 24. Large-Bore Gun Used in Fragment Tests

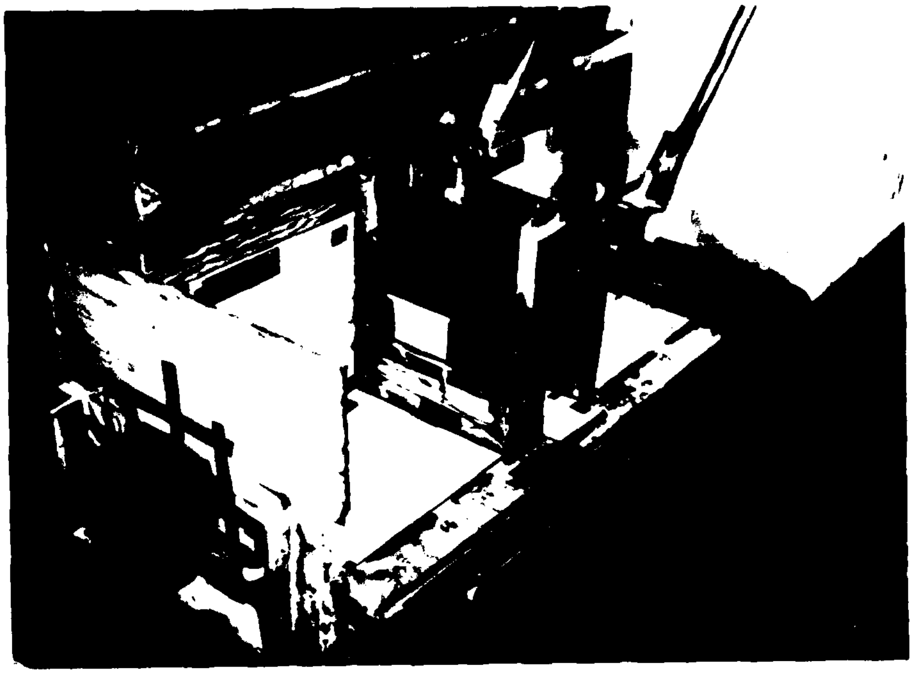


Figure 25. Typical Fragment Test Panel

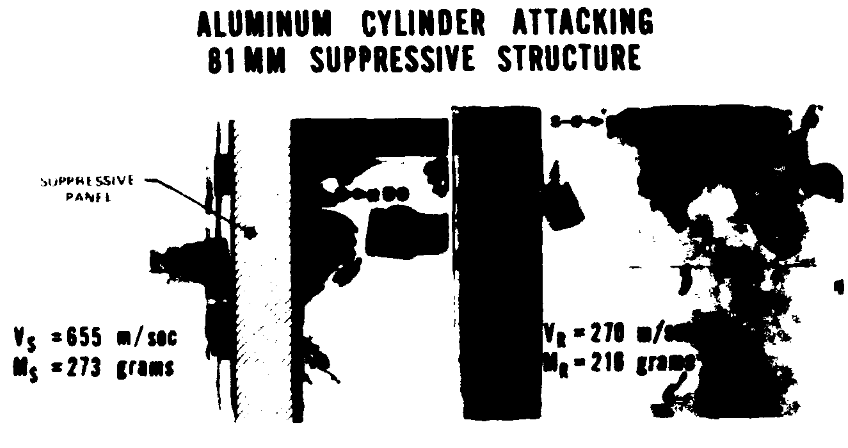


Figure 26. X-Ray of Aluminum Cylinder Attacking Suppressive Panel

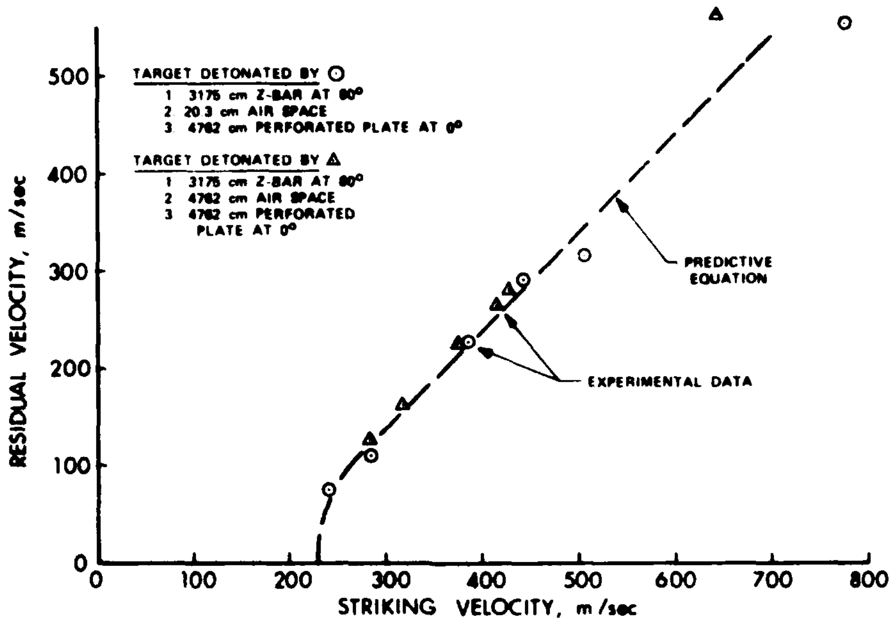


Figure 27. 273-Gram Aluminum (2024-T3) Cylinder
Attacking Spaced Target

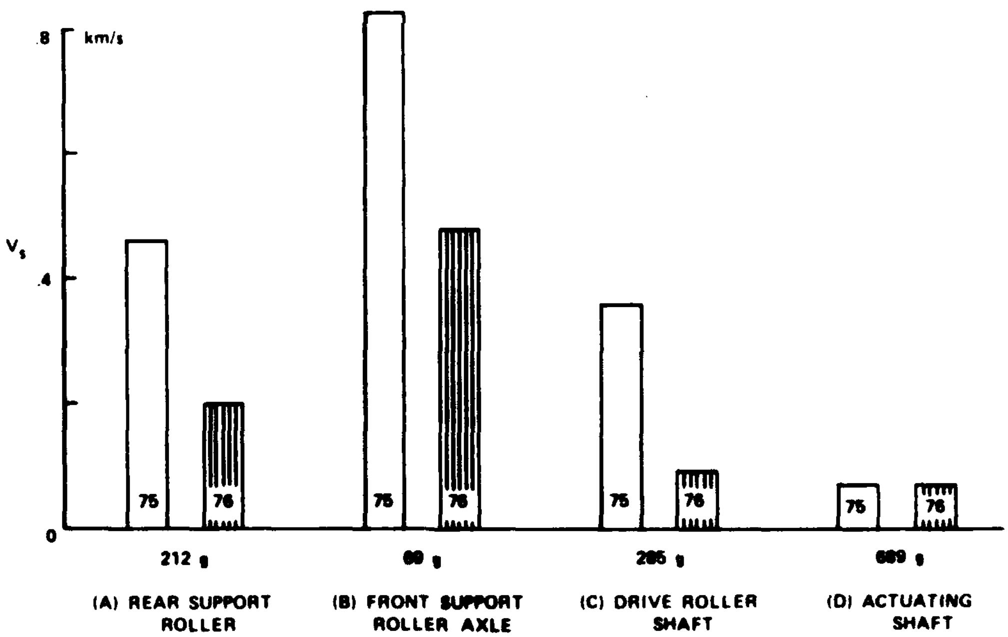


Figure 28. Secondary Fragment Limit Speeds
1975 (BRL IMR 332) Versus 1976
105-mm M1 Fuze Torque Operation

DISTRIBUTION LIST FOR TR-77013

Names	Copies
EDGEWOOD ARSENAL	
TECHNICAL DIRECTOR	
Attn: SAREA-TD-E	1
FOREIGN INTELLIGENCE OFFICER	1
CHIEF, DEMILITARIZATION/DISPOSAL OFFICE	
Attn: SAREA-DM-E	1
CHIEF, LEGAL OFFICE	1
CHIEF, SAFETY OFFICE	1
CDR, US ARMY TECHNICAL ESCORT CENTER	1
AUTHOR'S COPY, Manufacturing Technology Directorate	1
DIRECTOR OF BIOMEDICAL LABORATORY	
Attn: SAREA-BL-Q	1
Attn: SAREA-BL-R	1
DIRECTOR OF CHEMICAL LABORATORY	
Attn: SAREA-CL-B	1
Attn: SAREA-CL-C	1
Attn: SAREA-CL-P	1
Attn: SAREA-CL-T	1
DIRECTOR OF DEVELOPMENT & ENGINEERING	
Attn: SAREA-DE-S	4
DIRECTOR OF MANUFACTURING TECHNOLOGY	
Attn: SAREA-MT-M	1
Attn: SAREA-MT-TR	2
Attn: SAREA-MT-TS	5
DIRECTOR OF PRODUCT ASSURANCE	
Attn: SAREA-PA-A	1
Attn: SAREA-PA-P	1
Attn: SAREA-PA-Q	1
DIRECTOR OF TECHNICAL SUPPORT	
Attn: SAREA-TS-R	2
Attn: SAREA-TS-L	3
Attn: SAREA-TS-E	1
DEPARTMENT OF DEFENSE	
Administrator Defense Documentation Center Attn: Accessions Division Cameron Station Alexandria, VA 22314	12
Defense Supply Agency Attn: Mr. John Komos Cameron Station Alexandria, VA 22314	1
Chairman Department of Defense Explosives Safety Board Attn: COL P. Kelly, Jr. Forrestal Bldg GB-270 Washington, DC 20314	5
DEPARTMENT OF THE ARMY	
HQDA (DAMO-ODC) WASH DC 20310	1
HQDA (DAEN-MCC-I/Mr. L. Foley) WASH DC 20314	1
HQDA (DAEN-MCE-D/Mr. R. Wight) WASH DC 20314	1
US ARMY MATERIEL DEVELOPMENT AND READINESS COMMAND	
Director US Army Materiel Development and Readiness Command	
Attn: DRXOS-TA/Mr. Olson	1
Attn: DRXOS-ES/Mr. Myers	1
Field Safety Activity Charlestown, IN 47111	
Commander US Army Materiel Development and Readiness Command	
Attn: DRCCG	1
Attn: DRCRD-WB	1
Attn: DRCSF/Mr. W. Queen	2
Attn: DRCPM-CS/COL Morris	1
5001 Eisenhower Avenue Alexandria, VA 22333	
Project Manager for Chemical Demilitarization and Installation Restoration Attn: DRCPM-DR, Bldg E4585 APG-Edgewood Area	2
Project Manager for Munitions Production Base Modernization and Expansion US Army Materiel Development and Readiness Command Attn: DRCPM-PBM-EC/Mr. A. Dybacki Dover, NJ 07801	3
Director US Army Materiel Development and Readiness Command Intern Training Center Attn: Dr. G. Chiang Red River Depot Texarkana, TX 75502	1
US ARMY ARMAMENT COMMAND	
Commander DARCOM Ammunition Center	
Attn: SARAC-DE/Mr. J. Byrde	1
Attn: SARAC-DEM/Mr. Huddleston, Mr. Sumpterer	2
Bridge and Tacony Sts. Philadelphia, PA 19137	

DISTRIBUTION LIST FOR TR-77013 (Contd)

Names	Copies
Commander US Army Armament Command Attn: DRSAR-EN/Mr. Ambrosini	1
Attn: DRSAR-SC/Dr. C. Hudson	1
Attn: DRSAR-SF/Mr. R. Young, Mr. J. Varcho	2
Attn: DRSAR-IMB-C/Mr. Serlin, Mr. T. Fetter	2
Attn: DRSAR-IMB-C/Mr. S. Porter, Mr. A. Madsen	2
Attn: DRSAR-IMB-C/Mr. G. Cowan, CPT Burnsteel	2
Attn: DRSAR-IMB-C-A/Mr. L. Nelson Rock Island, IL 61201	1
Commander Frankford Arsenal Attn: Mr. Fidel, Mr. E. Rempler Bridge and Tacony Sts. Philadelphia, PA 19137	2
Commander Picatinny Arsenal Attn: SARPA-MT/Mr. Saffian, Mr. Canavan	2
Attn: SARPA-MT/Mr. Hickerson, Mr. Forsten Dover, NJ 07801	2
Joint Army-Navy-Air Force Conventional Ammunition Production Coordinating Grp US Army Armament Command Attn: Mr. E. Jordan Rock Island, IL 61201	7
Commander Cornhusker Army Ammunition Plant Grand Island, NE 68801	1
Commander Indiana Army Ammunition Plant Charleston, IN 47111	1
Commander Iowa Army Ammunition Plant Burlington, IA 52502	1
Commander Joliet Army Ammunition Plant Joliet, IL 60436	1
Commander Kansas Army Ammunition Plant Parsons, KS 67357	1
Commander Longhorn Army Ammunition Plant Marshall, TX 75671	1
Commander Lone Star Army Ammunition Plant Texarkana, TX 75502	1
Commander Louisiana Army Ammunition Plant Shreveport, LA 71102	1
Commander Milan Army Ammunition Plant Milan, TN 38358	1
Commander Radford Army Ammunition Plant Radford, VA 24141	1
Commander Sunflower Army Ammunition Plant Lawrence, KS 66044	1
Commander Lake City Army Ammunition Plant Attn: Mr. J. Jacobi Independence, MO 64056	1
Commander Ravenna Army Ammunition Plant Ravenna, OH 44266	1
Commander Pine Bluff Arsenal Pine Bluff, AR 71611	1
US ARMY TEST AND EVALUATION COMMAND	
Record Copy CDR, APG Attn: STEAP-AD-R/RHA APG-Edgewood Area, Bldg E5179	1
CDR, APG Attn: STEAP-TL APG-Aberdeen Area	1
Commander US Army Test & Evaluation Command Attn: DRSTE-FA APG-Aberdeen Area	1
Commander Dugway Proving Ground Attn: Mr. P. Miller	1
Attn: Dr. Rothenburg Dugway, UT 84022	1
DEPARTMENT OF THE NAVY	
Commander Naval Ordnance Systems Command Attn: Code ORD 43B/Mr. A. Fernandes Washington, DC 20360	1

DISTRIBUTION LIST FOR TR-77013 (Contd)

Names	Copies
Commander Bureau of Naval Weapons Department of the Navy Attn. Code F121/Mr. H. Roylance Washington, DC 20360	1
Commander Naval Ship Research & Development Center Attn: Code 1747/Mr. A. Wilner Bethesda, MD 20034	1
Commander Naval Explosive Ordnance Disposal Facility Attn: Code 501/Mr. L. Wolfson Indian Head, MD 20640	1
Commander Naval Ordnance Systems Command NAPEC-Ammunition Depot Attn: ORD-04M/B/X-5/Mr. L. Leonard Crane, IN 47522	1
Commander Naval Surface Weapons Center White Oak Laboratory Silver Spring, MD 20910	1
Commander Naval Weapons Laboratory Attn: Mr. F. Sanches Dahlgren, VA 22448	1
Commander Naval Sea Systems Command Washington, DC 20315	1
DEPARTMENT OF THE AIR FORCE	
Commander Explosives Safety Division Attn: ADTC/SEV/Mr. R. Allen Eglin AFB, FL 32542	1
HQ, Armament Development & Test Center Attn: DOM/Mr. S. Reither Eglin AFB, FL 32542	1
Commander Rocket Propulsion Laboratory Attn: Mr. M. Raleigh Edwards AFB, CA 93523	1
HQ, Ogden ALC/MMWRAT Attn: Mr. Cummings Hill AFB, UT 84406	1
Commander Norton AFB Attn: AFISC-SEV/Mr. K. Collinsworth San Bernardino, CA 92409	1
Commander Air Force Civil Engineering Center Attn: AFCEC-DE/LTC Walkup Tyndall AFB Panama City, FL 32401	1

Names	Copies
HQ, Air Force Logistics Command Attn: MMWM/CPT D. Rideout Attn: IGYE/Mr. K. Shopher Wright-Patterson AFB, OH 45433	 1 1
ADDED ADDRESSEES	
Director US Army Materiel Systems Analysis Activity APG-Aberdeen Area	3
Director US Army Ballistics Research Laboratories Attn: Mr. R. Vitali APG-Aberdeen Area	5
Division Engineer US Army Engineer Division, Huntsville Attn: HNDED/CS/Mr. Dembo Attn: Mr. W. Char PO Box 1600, West Station Huntsville, AL 35807	 1 1
US Army Engineer Division Waterways Experimental Station PO Box 631 Vicksburg, MS 39180	1
Deputy Manager for Engineering Atomic Energy Commision Attn: Mr. W. H. Jackson PO Box E Oak Ridge, TN 37830	1
US Department of Transportation Office of Hazardous Materials Operations Attn: Mr. Erskine Harton, Jr Transpoint Bldg 2100 Second St SW Washington, DC 20590	1
Mr. Frank Neff Mound Laboratory Monsanto Research Corp Miamisburg, OH 45342	1
Dr. W. E. Baker Soutwest Research Institute San Antonio, TX 78284	1
Division Engineer US Army Engineer Division Fort Belvoir, VA 22060	1
Chief Edgewood Arsenal Resident Laboratory NASA National Space Technology Laboratories Bay St. Louis, MS 39520	2